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ADP010817

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COSMO - SkyMed Mission Overview

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SUMMARY: COSMO - SkyMed is an end-to-end Earth Observation System dedicated to the remote sensing and data exploitation for Dual (military and civil) Use applications.
Main mission objective is therefore the provision of data, products and services relevant to the:

- **monitoring, surveillance and intelligence applications of MoD entities;**
- **environmental monitoring, surveillance and risk management applications of institutional entities;**
- **environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications of other institutional, scientific and commercial entities.**

The program, presently funded by the Italian Space Agency (ASI), has been conceived since its very beginning to be implemented within an international scenario covering both the development of the infrastructures and utilisation of the system.
Purpose of this paper is to present an overview of the mission, the dual use concept design drivers, the current system architecture, the possible co-operation scenario, the deployment strategy and the current schedule.

INTRODUCTION

COSMO-SkyMed is an end-to-end Earth Observation system dedicated to the remote sensing and data exploitation for Dual (military and civil) Use applications.

COSMO-SkyMed is composed by space, ground and service segments.

Main mission objective is therefore the provision of data, products and services relevant to the:

- monitoring, surveillance and intelligence applications of MoD entities;
- environmental monitoring, surveillance and risk management applications of institutional entities;
- environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications of other institutional, scientific and commercial entities.

According to the user needs analysis the mission ask for a correct mix of Optical and SAR sensor observations.

The most required spectral characteristics are microwave (X-Band synthetic aperture radar, X-SAR), panchromatic (visible band, VIS), multispectral (VIS, near infrared band, NIR, short wave infrared band, SWIR) and hyperspectral (VIS, NIR, thermal infrared, TIR).

Moreover, the dual use scenario calls for a mission which implements in an harmonic fashion several different modes of operation, characterised by a different priority with a suite of multi - mode / flexible sensors with an high thematic content, allowing to meet the military and the civil objectives at the same time.

In this scenario, the development of new/innovative instrumentation in the radar field (e.g., multi-mode synthetic aperture radar's with a, very high resolution and a very high level of flexibility) and in the optical field (e.g. hyper-spectral sensor with variable spatial resolution and high sensitivity capability in the visible and infrared) have been included in the objectives of dedicated technological developments [1].

Because of its valuable panel of flexible, heterogeneous and complementary sensors, the COSMO-SkyMed mission belongs to the next generation of Earth observation systems for which innovative processing methodologies must be also considered [2].

In fact, the synergistic use of the numerous available sensors, which can be achieved by data fusion, allows to merge their advantages in order to obtain a richer information and to it reduces the uncertainty associated with the data from individual sensors.

Paper presented at the RTO SET Symposium on "Space-Based Observation Technology", held on the Island of Samos, Greece, 16-18 October 2000, and published in RTO MP-61.

USER NEEDS

User needs, which can be benefit from space remote sensing techniques, have been identified, together with the relevant requirements.

It is worth to underline that the most important user needs are related to defence, national security and risk management applications, where space resources can provide a significant contribution to improve the tactical and strategic intelligence capability, minimise the vulnerability to disasters, et cetera.

In particular, risk management is evolving from pure post accident activities to prevention, preparedness and mitigation of crisis, so increasing the role of pre-crisis activities in order to avoid or mitigate the consequences of a disaster.

In this perspective risk management implies the applications relevant to the environmental monitoring and surveillance and can be subdivided into three major phases (namely, knowledge & prevention, warning & crisis and post crisis phases), each one having its own information and timeline needs.

Therefore the COSMO-SkyMed main civil applications can be identified in the disciplines of risk management, geology, forestry and agriculture, marine & inland water, ice, land use, landscape ecology, law enforcement, et cetera.

As an example, during the warning and crisis phases of the risk management, the users ask for images "as prompt as possible", "as accurate as possible" and "as synoptic as possible". In particular during such a phase the highest impact for disaster monitoring is accomplished if, few hours after the event, data are acquired over wide areas with low resolution. After such a period it is more relevant to acquire narrow swath coupled to very high resolution data.

Moreover, high resolution images with large swath are of great value also for routinary services, as topography updating, urban areas maps, land use maps at large scale, etc.

Most of these products are requested also for commercial purposes.

DUAL USE OPERATIONAL REQUIREMENTS

As previously mentioned, the system shall be able to support a Dual Use scenario which foresees various user classes both military and civilian in a national and international context.

In other words the system shall be able to provide the required/agreed level of service to each user, asking for the capability to be configured in a flexible and expandable way for supporting new users.

The system overall co-ordination function shall be centralised (and based on priority rules).

To adequately support a Dual Use utilisation scenario main design criteria have been identified and here below summarised:

- Direct Control of the National Resources, control of the deployed infrastructures, management of the necessary operation to keep the system functional, including planning of the mission and compilation of the priority acquisition, if necessary.

- Interface with Different Class of Customers, the system shall interface with:
  - *High Priority Customers*, as privileged users of the system.
  - *Standard Customers*, as routine users of the system.

- Management of conflicts, the system shall be able to resolve conflicts relevant to the planning on the basis of specified priorities and agreed procedures
  The system shall be able to accept two type of user requests:
  - *High priority Customers requests*
    - The system shall be able to accept up to N high priority requests per day.
    - The N high priority requests prepared by the military/institutional user, shall be always included in the overall task schedule to be executed by the system.
  - *Standard Customers requests*
    - These requests are characterised by a relatively long response time. Therefore, routine requests shall be included in the medium/long term planning of the system.
    - In case of conflict between the military, institutional and /or commercial routine requests the corresponding time deadline associated to each request will be used as key parameter to solve the conflict.

- Approval of the tasking. The system shall be able to implement the current acquisition constraints given by National Security Authorities.

- Integrated Co-ordination and Planning Entity, the system has to foresee a co-ordination and planning entity devoted to co-ordinate and harmonise, from an operational point of view, the different requests coming from the different users.

- Military Observer , military representatives could be located at the national and at the integrated planning facility with the specific task of checking the correct implementation .of the procedures.

- Confidential nature of the information, the system shall guarantee the confidential nature of acquisition request (both high and low priority) and the integrity of the information.

- Data Encryption, the command up-linked to the satellites, as well as all the down-linked data has to be encrypted.

- Restricted access to the activity schedule, the planned and the final schedule shall be restricted to authorised personnel.

COSMO-SKYMED ARCHITECTURE

COSMO-SkyMed mission will be based on a multi-satellite Earth observation system acquiring remote sensed data of very high quality from the spectral, temporal, spatial and radiometric points of view.

In particular, the fulfilment of the mentioned dual use applications calls for the following general performance characteristics:

- fast response time (up to the final users)
- very good image quality, to allow a robust image interpretability at the requested scale of analysis
- all weather and day/night acquisition capability
- collection of large areas during a single pass capability
- along-track stereo during a single pass capability
- global coverage
- acquisition of a sufficiently large and interpretable image in a single pass
- acquisition of homogeneous and comparable multi-temporal data set, characterised by adequate spatial and spectral resolution suitable to perform analyses at different scales of detail

Space Segment

The COSMO-SkyMed space segment is based on a constellation of seven small satellites combined with a fast data reception capability. Such a provision of data on an operational basis with the associated implications of continuity and quality is an essential characteristic of the system.

Three satellites of the constellation carry optical instruments such as a panchromatic camera, a multispectral camera and a hyperspectral camera, providing imagery with a valuable information content.

The four other satellites are equipped with a Synthetic Aperture Radar (SAR) to give an insight in the microwave range and, consequently, to provide all weather and day/night acquisition capability unreachable by optical sensors, but at the price of a more limited spectral information content.

The constellation will be deployed in two orbital planes (one orbit plane for optical satellites and one orbit plane for SAR satellites) allowing to the SAR satellites the collection of the maximum solar radiation (sun-synchronous dawn-dusk) to face their relevant power demand and to optical satellites to operate the in stationary illumination conditions (sun-synchronous near noon). optimising the imaging performance.

The orbit parameter have been selected taking into account the following additional aspects:

- Optimisation of the revisit time interval versus the number of the satellites;
- Implementation of incidence angle diversity;
- Global accessibility starting from one operating satellite.
- Graceful degradation in case of failure of one or more satellites;
- Optimisation of the mission lifetime versus the sensor achievable performances in term of radiometric resolution of the microwave instrumentation and spatial resolution of the optical instrumentation;

Therefore, the best promising constellation has been identified and the relevant characteristics are here below summarised [3].

SAR Satellites Selected Orbit
Orbit: Dawn-dusk SSO
Total satellite Number: 4
Altitude: ≅ 600 km
Revisit Time: 12 hours

Optical Satellites Selected Orbit
Orbit : Near-noon SSO
Total satellite Number: 3
Altitude: ≅ 600 km
Revisit Time: 24 hours

The SAR Payload is an X-band Radar which offers the best compromise among several constraints due to the application requirements, technological issues, mission target cost etc.

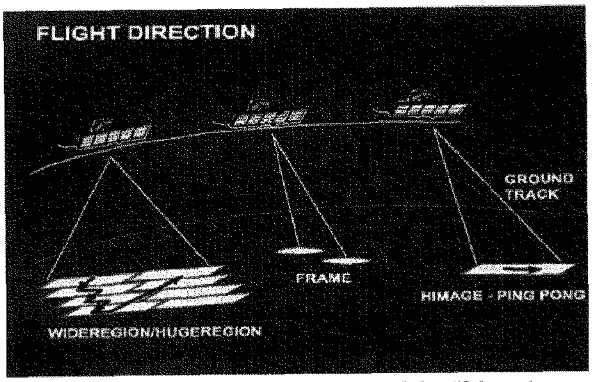
The fundamental characteristics of the Synthetic Aperture Radar instrument operative modes are summarised as follows:

Modes with one polarisation selectable among HH, VV, HV or VH:

- FRAME
  - resolution: order of the m and less
  - spot width: several tens of km^2
- HIMAGE
  - resolution: few m
  - swath width: several tens of km
- WIDEREGION
  - resolution: few tens of m
  - swath width: hundreds of km
- HUGEREGION
  - resolution: several tens of m
  - swath width: few hundreds of km

Modes with two polarisation selectable among HH, VV, HV or VH:

- PING PONG
  - resolution: few m
  - swath width: several tens of km



Fundamental characteristics of the X-band Synthetic Aperture Radar Payload operative modes

The main SAR Payload characteristics which will necessitate technological consideration throughout the duration of the relevant development activities are:

- spatial resolution and flexibility of the operative modes, developing and qualifying an X-band active antenna with range and cross-range steering capabilities;
- development and qualification of low mass and low power consumption technologies to make consistent the accommodation on small platforms.

The principle items which are affected by critical technologies are listed hereafter gathered for each Radar S/S:

- *Antenna*
  - Multi Polarisation Radiating panel
  - T/R Modules
  - Tile Digital controller
  - Tile power supply
  - Mechanical structure
  - Hold-down and release mechanism
  - Deployment mechanism
- *Radio Frequency S/S*
  - Up Conversion/Down Conversion Chains
  - Frequency Generation Unit
  - Calibration Network
- *Radar Signal Conditioning:*
  - Wide Band Chirp Generator
  - High Speed Analogue-to-Digital Converter
  - Hi-Rate Data Formatting Section
- *Instrument Control S/S*
  - Core Control Unit
  - Time Base Generator
  - Master Beam Controller

The High Resolution Panchromatic and Multispectral Camera (HRC) is designed to provide high spatial resolution images of the exposed risk area in order to support the defence, national security and risk management applications. The HRC is also capable to take a large area of the entire scene with a single pass using a mosaic technique.

The Hyperspectral Camera (HYC) is mainly devoted to the water pollution management, vegetation mapping and geological application. These activities are of great importance to assess the vulnerability of the environment during the knowledge and prevention phase of the natural and anthropic risk management. The TIR channels are devoted to monitor surface, sea temperature, forest fires and volcanic activities.

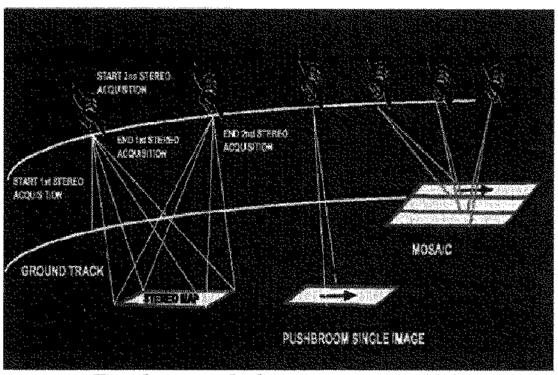
The fundamental characteristics of the optical instrument operative modes are summarised as follows:

High-Resolution Camera:

- Type:
  push broom imager operating in 6 different and simultaneous spectral channels
- Multispectral bands and resolutions:
  1: 0.5-0.90 μm (PAN) order of the m at nadir
  2: 0.45-0.52 μm (blue) few m at nadir
  3: 0.52-0.60 μm (green) few m at nadir
  4: 0.63-0.69 μm (red) few m at nadir
  5: 0.76-0.90 μm (NIR) few m at nadir
  6: 1.55-1.75 μm (SWIR) few m at nadir
- Swath : tens of Km
- Access region :-/+ 35° (across-track)

Hyperspectral Camera:

- Operational modes:
  Wide mode - Low resolution
  Narrow mode - High resolution
- Resolutions: 20 m to 300 m (VIS, NIR)
  50 m to 300 m (IR)
- Swaths: 20 Km to 300 Km
- Access region: -/+ 35° (across-track)



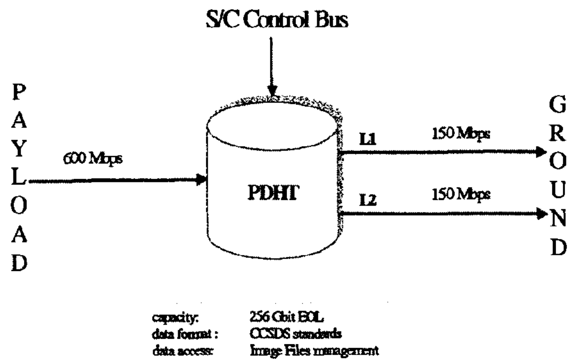
Fundamental characteristics of the Optical Payloads operative modes

Payload Data Handling and Transmission

The PDHT comprises all functions necessary for the real-time acquisition, storage and handling of science data generated by the Payload, and for their transmission to the ground station.

The PDHT shall provide the following Mission Modes of operation:

- Store Only: Payload Data currently acquired (Image Segment File) are stored .
- Down-Link Only: Payload data previously stored (Image Segment Files) are down-linked (play-back).
- Store and Down-Link: Payload Data currently acquired (Image Segment File) are stored, and simultaneously Payload data previously stored (Image Segment Files) are down-linked.
- Pass-Through: Data currently acquired (Image Segment File) are down-linked in near real-time on one of the two Links (L1 or L2).



PDHT Configuration: Data Volume and Data Rate

Spacecraft Bus General Architecture

The Spacecraft Bus functions can be summarised as follows:

- to support the Payload mass (on ground, during launch and in orbit);
- to keep the Payload at the right temperature.
- to put the Payload in the right orbit and keep it there;
- to provide correct pointing to the Payload;
- to provide the requested electric power to the on-board equipment and instruments;
- to provide interface with ground through telecommands and telemetry.

All the above functions have to be provided to comply with the spacecraft bus needs themselves, too.

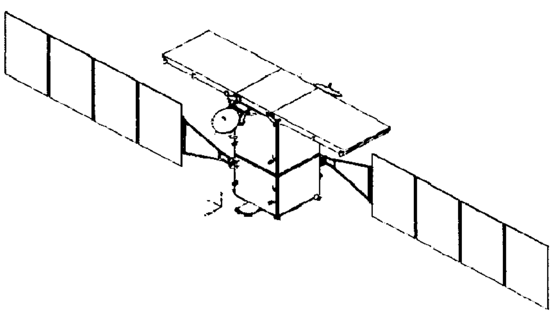
Here below the Spacecraft Bus subsystems main architectural features are recalled:

- Structure S/S: Structural Frame by machined aluminium with aluminium Sandwich Panels.
- Thermal Control S/S: Passive Control System augmented by use of Heaters.
- Integrated Control S/S (ICS), including the Attitude and Orbit Control (AOC) and the Data Handling (DH) functions.
- Propulsion S/S: Mono-propellant (Hydrazine) Blow-Down System.
- Electrical Power S/S: Unregulated Bus (23-35 V) with NiH2 Battery and GaAs Cells Solar Array.
- TT&C S/S: Standard totally redounded S-Band Transponder with Antenna.

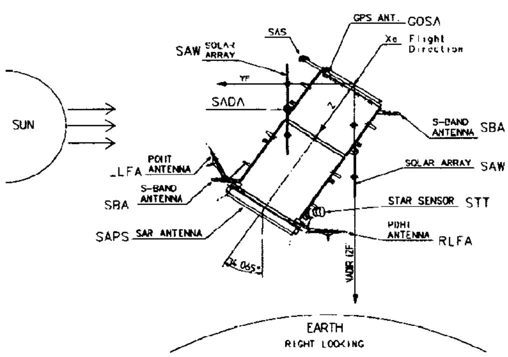
The nominal attitude of the optical satellite is nadir pointing, with a fast repointing capability up to ± 20° in the pitch axis and ± 35° in the roll axis, according to the various imaging modes.

The attitude control of the SAR satellite is in charge for the SAR antenna boresight pointing at ≅ 38° of incidence on the right side of the ground track, for the yaw steering of +/- 2 ° (with orbital cycle) and for the repointing of antenna boresight also on- the left side (mode available for a limited time interval to improve the accessibility and to support emergency requests).

The pointing accuracy and knowledge are quite stringent due to the high resolution and imaging quality of the embarked sensors.



SAR Satellite in the deployed configuration



SAR Satellite in the orbit configuration

Ground Segment

The COSMO/SkyMed ground segment provides all the infrastructures needed to support the COSMO/SkyMed Mission in the Dual Use scenario.

It is devoted to perform the main functions/operations at ground level needed to manage the COSMO-SkyMed mission both in terms of constellation control and global data management.

The COSMO-SkyMed ground segment components located out to fulfil the high level requirements of the COSMO/SkyMed mission are the following:

- One Mission Planning and Control Centre (CPCM) which is in charge of co-ordinate on-board and ground activities, perform overall mission planning, allocate resources and solve conflicts;
- One Satellites Control Centre (CCS) which provides all the functions devoted to Monitor & Control the satellite constellation (including Flight Dynamics operations);
- TT&C Stations (directly controlled by the CCS and not necessarily co-located with it) which provides the primary link service between the COSMO/SkyMed Satellites and the Ground Segment;
- One or more Civil facilities which are devoted to manage Civil User requests, to acquire, archive, process and deliver the data received from the COSMO-SkyMed Satellites by means of co-located and/or remotely located X-band acquisition stations;
- One or more Military facilities, having own capabilities for the Payload data acquisition, archiving and processing.

A dedicated communication network will guarantee the connections between the different COSMO-SkyMed Centres/Stations in a secure, reliable and efficient way.

Service Segment

The nature of the service is quite variable w.r.t the application field and must be designed and implemented taking into account the peculiarities of each application. The key points related to service segment needs addressed by end-users in the field of risk management, having very stringent peculiarities, are :

- the access to information products derived from EO data: this access should be easy and fast, and from the point of view of end users, totally transparent with regard to EO data sources – i.e. data providers;
- the suitability and the accuracy of information products: this concern implies that the quality of the generated products is checked in order to assess their relevance compared to the initial user requirements, taking into account the limitations related to the characteristics of current space missions and image processing algorithms;
- the reproducibility: it is important for the customers that an approach, which has been successfully applied in one case, can be used

for another area. This point not only concerns the image processing algorithms themselves, but also the selection process applied to identify the relevant EO data or the type of ancillary data used to reach the required information product;

- the reliability and the robustness of the service: some users put the emphasis on the fact that the service must be available 24 hours a day and 365 days a year. Their own activity is related to crisis phase and may require information at any moment and with the shortest delivery time.

The following concepts are considered as design drivers:

Service Continuity: For many applications (e.g. defence applications, risk management, marine and coastal observation) the service must be available 24 hours a day and 365 days a year, for any activities related to crisis phase and which require information at any moment and with the shortest delivery time.

Space based Geo-Information must be obtained and secured in all weather and day/night conditions.

One of the most stringent requirements is the fast reaction in case of a disaster.

However this imply that at user site there is an operational entity which can interact with the system to require the acquisition of data. This also implies that the system is integrated in the decision process of the crisis management. Therefore, as an example, in case of an earthquake, the request for acquisition has to be issued very quickly, even before that epicentre is exactly determined. This imply the definition of an operational procedure within risk management entities to fully exploit the provided services and the implementation of specific means HW and SW in the system to support the operations. In this case, the distribution of a part of the processing capability to the user facilities could be a solution. In this perspective, the crisis management centres could be equipped with terminals able to order, acquire, provide quick-look images and process the data up to the level suitable for interpretation.

Archiving: The amount of data to be archived depends on the type of application.

In the case of risk management, land use mapping is a major activity used as a component of the vulnerability to create risk maps. In this activity, radar or optical raw data and intermediate products must be archived. Concerning optical data only images with less than 10-20% cloud shall be archived. Some argue that only warning images (just before the crisis) must be archived. This option seems to be too restrictive as it is necessary to archived damage images and normal situation images. Therefore, the archiving facilities shall supply the customers with a recent image at the best quality. Then, these images will be used as reference data with eventually additional images acquired during the crisis.

In the case of risk management, again, for areas where a high level of risk can be detected (historical events reasons), some final products should be archived in order to have very quickly a product which allows comparison during the crisis and just after. Other specific areas must take into consideration and be archived as Final end-user products such as River and intermediate surrounding, increased urbanisation areas (e.g. rural/urban boundaries), etc. For these reasons, the archiving facilities shall describe these specific areas in order to provide, when requested, data that allowing to identify rapidly the potential vulnerable areas. This is an important feature of the archiving for the updating of the Risks & Vulnerability maps and may be less costly than a full Land Use/Cover product.

The multi-temporal acquisition feature raises the problem of the complexity of the requests. In order to facilitate the user requests, the archiving facilities shall archive together (i.e. with a same event reference) all the data worked out before, during and after the crisis. This will facilitate the retrieve operations and give a full set of data to the customers.

Confidential Archiving facilities of the sell products must be supported.

Cataloguing: This is an important issue of accessing the service. The catalogue access must be very efficient (time constraints) and Internet (web sites) seems to be the current better solution excepted in case of crisis where powerful and secured means shall be provided. Nevertheless, the data access in case of crisis must remain with the same user interface (what ever the request) but will include "short cut" in order to improve the access delay and to manage the priority requests. The hardware and/or software means used in these situations must remain totally transparent for the users. Confidential cataloguing facilities of the sell products must be supported.

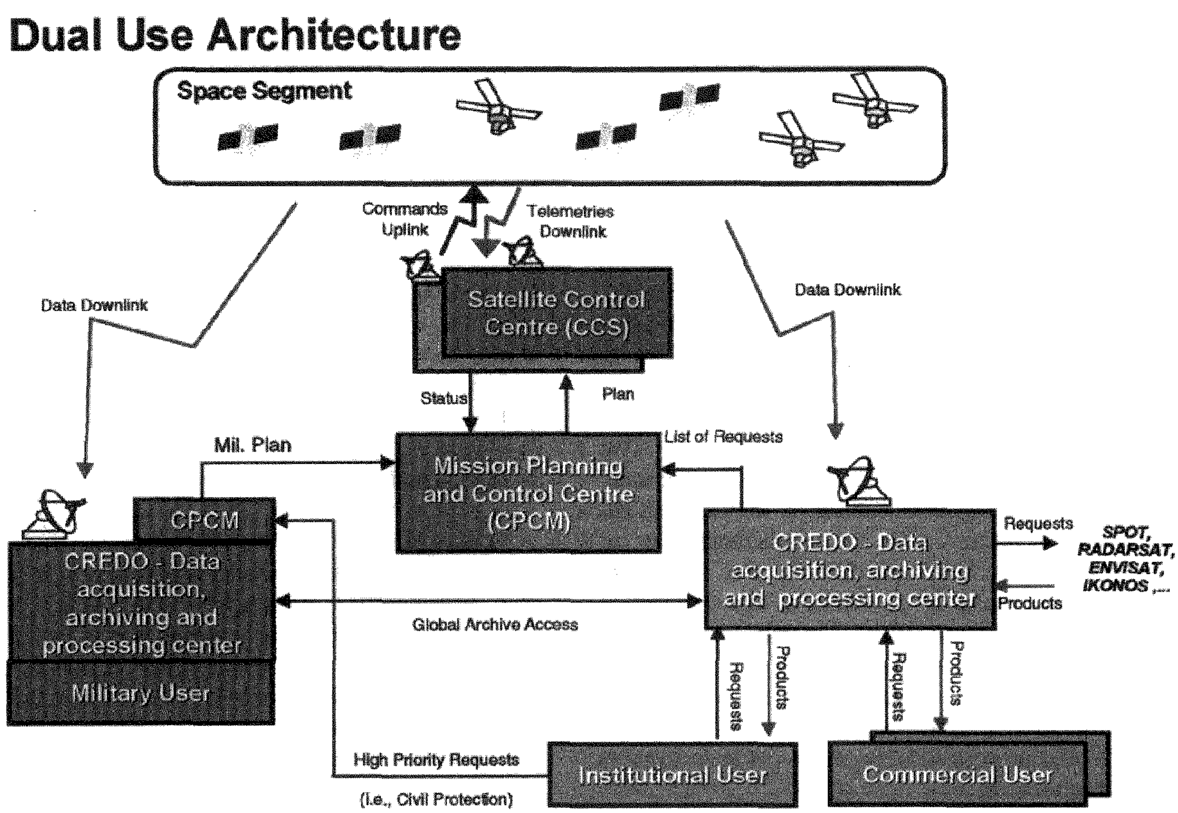
Priority: In general, serving a various and large number of customers, necessitates a queue management process. This is generally based on demands priority classification . Priorities need to be determined by events and the need for priority is related to urgency in the crisis phase. In this case, the following criteria are to be considered: the estimated duration of the crisis, the size and the location of the area, the availability of archive data, etc. These requirements will impact directly on the priority management facilities at different levels:

- planning of new acquisition ;
- priority of processing ;
- priority of delivery (in particular when the real-time product is requested) ;

Customisation: The goal is to have as much as possible off the shelf products, but in some cases customisation might be necessary. Identify rough estimates of customised products with respect to standard products to different types of customers, in the same application field). This will permit to identify the necessity to implement or not development facilities.

Data Dissemination: Risk management when a crisis occurs, requires fast reaction, which can be guaranteed much better in case of direct broadcast of sensed data to the crisis management centre. The satellites using access security features (e.g. encryption keys to guarantee the information) will broadcast only data acquired by sensors providing useful information for crisis management.
However some products may require direct "in-situ" product delivery. This raises the problem of the size of the data to be transmitted and the geo-location and calibration in case of providing data with reception capability directly from the satellite.

COSMO-SkyMed overall conceptual architecture is shown here below.



CO-OPERATION SCENARIO

The COSMO-SkyMed program, presently funded by the Italian Space Agency (ASI), has been conceived since its very beginning to be implemented within an international scenario covering both the development of the infrastructures and the utilisation of the system.

As far as the COSMO-SkyMed system infrastructures development is concerned, which includes both the on-board and the ground segments, it has been planned to enlarge the participation to the program to other interested countries through multilateral agreements.

According to this policy ASI has started several bilateral formal contacts in order to identify and define the level of interest and potential involvement of other national space agencies/authorities, provided that the Italian leadership is maintained and there is a technical, programmatic and commercial convergence towards the objectives established by ASI.

Additional approaches have been initiated for the international participation policy with the aim to identify any possible partner, outside of Italy, which is interested to the contribution on the system, providing the requested capabilities and technologies to cope with system targets.

The COSMO-SkyMed international co-operation scenario is driven by the following considerations:

- The characteristics of the COSMO-SkyMed System are such to satisfy not only European continent focused on the Mediterranean basin user needs, but also the overall world.
- The overall European Earth Observation market looks to be very promising and a globalisation of the system will allow an easier and faster utilisation with the relevant economical benefits for the COSMO-SkyMed initiative.
- Referring to the COSMO-SkyMed System infrastructures development, it has been planned to extend the participation to the program to other countries, provided they show interest, through multilateral agreements.

In addition to above, additional bilateral contacts have been initiated.

According to this policy ASI started several formal contacts in order to identify and define the level of interest and potential involvement of other national space agencies or authorities.

In particular, further to a meeting held between ASI and DLR (German Space Agency), it has been decided that potential co-operation between Italy and Germany in the frame of COSMO-SkyMed program should also be investigated at industrial level.

CNES has interacted with ASI as far as a French participation to the program is concerned. In particular the technology available in their industries is such to orient the contribution to a role of primary interest for the optical space segment.

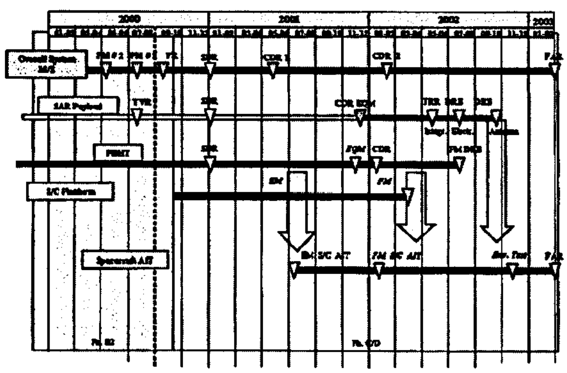
The system is the candidate solution for the European earth observation needs of the WEU

DEPLOYMENT STRATEGY AND CURRENT SCHEDULE

The satellite constellation deployment strategy will be compatible with the main mission objectives users EO data demand and with the available funding and commercial market. However, as a general rule, the full constellation will be deployed within 20% of an individual satellite's lifetime.

However, being the top performance of the system (corresponding to the full constellation) gradually achieved stepwise, the above mentioned time limit for constellation build-up could be increased.

The current schedule of the first COSMO-Skymed SAR Satellite phase C/D activities is shown here below, together with the already closed phase B2 and the parallel technological programs.



COSMO-SkyMed Current Schedule

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